An Improved Methodology for Obtaining Jiles-Atherton Hysteresis Model Parameters

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An accurate material modeling is imperative for field calculations in order to assure reliable results. For hysteresis modeling the Jiles-Atherton approach has been broadly employed but it is strongly dependent on its parameter set to work appropriately. This paper presents an original methodology to obtain such parameters. From the model equations, two non-linear algebraic systems of five equations and five parameters are written. In order to validate the methodology, experimental data are compared to calculated ones. Simulations demonstrate that the proposed methodology obtain an accurate parameters set from experimental hysteresis loop with relative low computation effort.

***Index Terms*— Cauchy problem, Maclaurin series, magnetic hysteresis, magnetic materials.**

I. Introduction

THIS WORK deals with the determination of the five Jiles-Atherton scalar hysteresis model parameters m_s, k, α, a and c [1-3]. In [4] an original methodology to determine the five model parameters was presented. In that work an implicit formula was developed in which the magnetic induction B is written as a function of the magnetic field strength H as well as in terms of the derivative of B with respect to H. In that methodology derivatives computations are required, which can lead to numerical instability and increase in computational effort, especially if there are noises in experimental data. Despite these drawbacks, the approach was used to characterize several materials and good results could be obtained with satisfactory agreement between calculated and measured data.

The main contribution of this paper is to improve the methodology for obtaining the JA model parameters using an inverse model where the induction B is the input variable but, contrary to previously, avoiding the calculation of the derivatives.

The proposed approach is based on an associated Cauchy problem with the corresponding initial value obtained from appropriate experimental data. Moreover, the Cauchy problem [7] was solved by using the method of integrating factor applying Maclaurin series. To validate the proposed methodology, the parameters of the model are identified and comparisons between experimental and calculated results are carried out showing that the proposed procedure allows a more accurate modeling of the magnetic materials behavior.

II. Equation System

From the JA model a linear ordinary differential equation is written. Then the Cauchy problem associated to this differential form is considered. Its initial value is an experimental magnetic strength and induction pair H_0, B_0. The Cauchy problem is solved using an integrating factor and by parts integration. The obtained definite integral is then solved numerically by a Maclaurin series. More details concerning this development will be given in the full version of the work. The final equation is as follows

$$\begin{aligned}\frac{B}{\mu_0} - H = {} & \left[\frac{B_0}{\mu_0} - H_0\right] e^{\frac{\psi}{k\delta}} + (1-c)\frac{m_s}{k\delta} e^{\frac{\phi}{k\delta}} \times \\ & \sum_{n=0}^{\infty}\left\{\frac{c_n}{n+1}\left[\left(\frac{\alpha}{\mu_0}B - (\alpha-1)H\right)^{n+1} - \left(\frac{\alpha}{\mu_0}B_0 - (\alpha-1)H_0\right)^{n+1}\right]\right\} + \\ & c m_s\left[\operatorname{cotgh}\left(\frac{\frac{\alpha}{\mu_0}B - (\alpha-1)H}{a}\right) - \frac{a}{\frac{\alpha}{\mu_0}B - (\alpha-1)H}\right] - \\ & c m_s\left[\operatorname{cotgh}\left(\frac{\frac{\alpha}{\mu_0}B_0 - (\alpha-1)H_0}{a}\right) - \frac{a}{\frac{\alpha}{\mu_0}B_0 - (\alpha-1)H_0}\right] \times \\ & e^{\frac{\psi}{k\delta}}\end{aligned} \tag{1}$$

where

$$\begin{aligned} \psi &= \frac{\alpha}{\mu_0}B_0 - (\alpha-1)H_0 + \phi \\ \phi &= -\frac{\alpha}{\mu_0}B + (\alpha-1)H \\ c_0 &= a_2 / b_2 \\ c_1 &= (a_3 - c_0 b_3)/b_2 \\ c_2 &= (a_4 - c_0 b_4 - c_1 b_3)/b_2 \\ c_3 &= (a_5 - c_0 b_5 - c_1 b_4 - c_2 b_3)/b_2 \\ &\vdots \end{aligned} \tag{2}$$

It is important to notice that coefficients a_n, c_n are not the JA model parameters a, c. The coefficient a_n depends on the model parameters a, k and δ values. The coefficient b_n depends on the model parameter a. As long as the five parameters of the model are known, then (1) allows to calculate H for a given B or B for a given H. The absence of derivative is the most important aspect in this proposed methodology.

III. IDENTIFICATION OF THE MODEL PARAMETERS

Equations (1) are two non-linear equations in which the five JA model parameters appear. To obtain their values, two non-linear algebraic equation systems, each one with five equations and five unknowns should be written. Therefore, five experimental points at the ascending as well as at the descending branches of the experimental loop are used to write the systems. Since there is no required calculating derivative, there is no need to select this data unlike [4]. The system has infinite solutions and one of them represents the sample experimental behavior. In summary, to solve the equation system first select initial value H_0, B_0 in experimental data table, next vary the initial value of model parameter set and finally in case of divergence change initial value H_0, B_0.

IV. RESULTS

Two different hysteresis loops are considered: a noisy loop shown in Fig. 1 and a sigmoid-shaped one presented in Fig. 2. Their corresponding JA model parameters values are presented in Table I. In the same table the calculation times spent in obtaining them with a PC computer core i5, 2.67 versus 2.67 GHz are given.

TABLE I
RESULTS

	m_s (A/m)	α	a (A/m)	k	c
Noisy loop					
Initial value	2 x10^6	4 x10^{-4}	71	76	0.01
Solution	2.120x10^6	1.064x10^{-4}	69.40	90.20	0.119
time (s)	2.423				
Sigmoid loop					
Initial value	1.72 x10^6	1.7 x10^{-4}	129.8	195	0.47
Solution	1.673 x10^6	2.375 x10^{-4}	129.5	89.13	0.51
time (s)	4.311				

Notice that the parameters are fast obtained with a short processing time. It should also be noted that the minimum distance between experimental and calculated data is 0.02 for noisy loop and 0.002 for sigmoid loop, which shows the effectiveness of the implemented procedures.

Fig. 1 shows a comparison between simulation and experimental results for the noisy hysteresis loop. Here, the behavior of the proposed methodology is adequate. The sigmoid-shaped hysteresis loop is very well predicted as shown in Fig. 2.

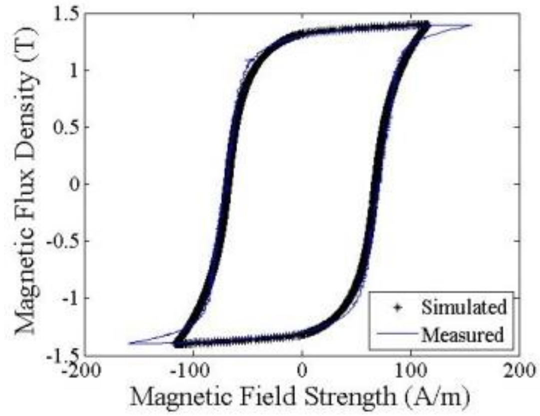

Fig. 1. Calculated and measured results: noisy hysteresis loop.

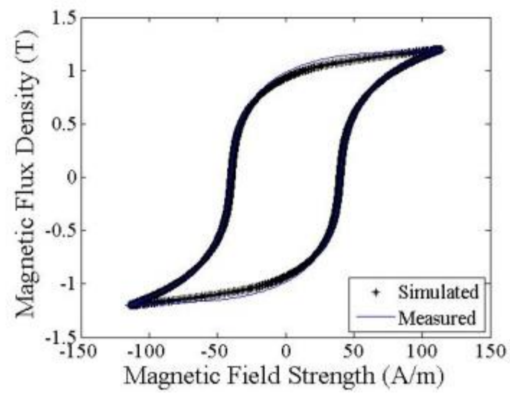

Fig. 2. Calculated and measured results: sigmoid hysteresis loop.

V. CONCLUSIONS

A new methodology for the evaluation of the JA hysteresis model parameters is presented in this work. The proposed approach improves the way these parameters are determined avoiding the use of derivatives and optimization procedures. It is fast and able to provide reliable hysteresis loops when compared to experimental ones. More results will be given in the full version of the paper.

VI. REFERENCES

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